AD-A132 180 MANNED TESTING OF THE SUPERLITE 17B DIVING HELMET COMPARED WITH THE MK 1 MOD S DIVER'S MASK(U) NAVY EXPERIMENTAL DIVING UNIT PANAMA CITY FL H J SCHWARTZ 1/1

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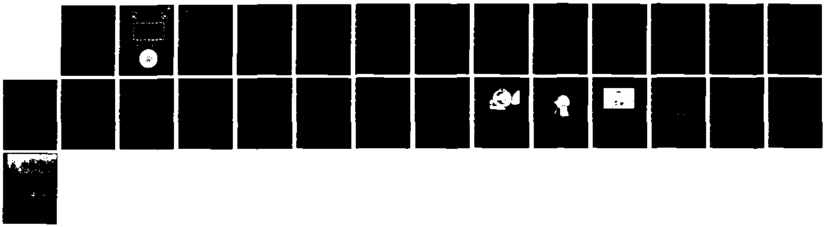

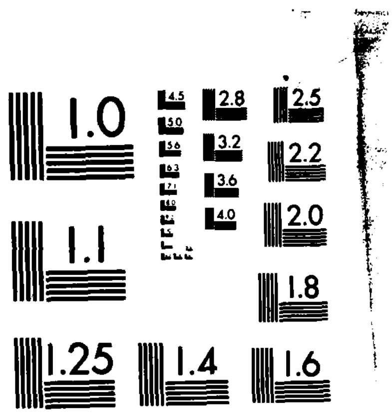
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REPORT NO. 4-83

MANNED TESTING OF THE SUPERLITE 17B DIVING HELMET COMPARED WITH THE MK 1 MOD S DIVER'S MASK

By

CDR H. J. C. SCHWARTZ, MC, USNR

JUNE 1983

NAVY EXPERIMENTAL DIVING UNIT

DEPARTMENT OF THE NAVY
NAVY EXPERIMENTAL DIVING UNIT
PANAMA CITY, FLORIDA 32407

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Submitted by:	Reviewed by:	Approved by:
H. J. C. Schwartz	E. D. Thalmann	Frank E. Eissing
H. J. C. SCHWARTZ	E. D. THALMANN	FRANK E. EISSING
CDR, MC, USNR	CDR, MC, USN	CDR, USN
	Senior Medical Officer	Commanding Officer

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ABSTRACT

The Diving Systems International Superlite 17B helmet underwent manned performance testing at a simulated depth of 850 feet of seawater during a helium-oxygen saturation dive in the Ocean Simulation Facility. The Navy MK 1 Mod S Diver's Mask was tested at the same time as a basis of comparison. Four subjects performed a total of 12 graded exercises (50-150 watts) on a submerged bicycle ergometer. Breathing characteristics of both UBA's were satisfactory and capable of supporting heavy exercise at 850 FSW. Maximum end tidal CO_2 in mmHg at 150 watts was 55.2 ± 5.9 in the Superlite 17B in a 45° head-up position, 48.0 ± 9.7 for the Superlite 17B in the 45° head-down position, and 57.5 ± 8.2 for the MK 1 Mod S Diver's Mask in the 45° head-up position. A microphone manufactured by the U.S. Navy was substituted for the Superlite 17B microphone and provided better communication at depth.

Key Words: Open-Circuit
Saturation
Helium-Oxygen
Exercise
Carbon Dioxide
Breathing Resistance
Underwater Breathing Apparatus

Manned Testing of the Superlite 17B Diving Helmet
Compared With The Mark 1 Mod S Diver's Mask

INTRODUCTION

The Superlite 17B (SL17) is a commercially available open-circuit surface supplied diving helmet produced by Diving Systems International (425 Garden Street, Santa Barbara, California). The Navy Experimental Diving Unit (NEDU) was given the task of evaluating the SL17 for possible use in the Navy's Deep Diving Systems (DDS) to replace the currently used MK 1 Mod S Diver's Mask (MK 1 Mod S). The SL17 offers the potential advantages of more protection and better communications due to the solid, dry helmet.

Unmanned testing of the SL17 at NEDU in 1979 (1) to 198 FSW using air showed that it met standardized NEDU performance goals (2) for work of breathing. In a more recent series of manned studies done in Canada at the Defence and Civil Institute of Environmental Medicine (DCIEM), CO_2 toxicity symptoms were seen due to poor oronasal sealing and rebreathing of gas from the helmet in some configurations (3).

This report describes the results of a series of manned tests of the SL17 at 850 feet of seawater (FSW) during a helium-oxygen saturation dive, DEEP DIVE '82 (NEDU Test Plan 82-50), at the NEDU Ocean Simulation Facility (OSF). Graded exercise studies were done with the helmet instrumented to study breathing characteristics under various work loads. Subjective evaluation of the helmet by the Diver-Subjects involved the communications, the neck dam, and the general feel of the helmet under various positions and work loads.

The MK 1 Mod S was tested under the same conditions as the SL17 in order to have a basis of comparison. No manned or unmanned studies have been done on the MK 1 Mod S since it is mechanically similar to the MK 1 Mod 0 Diver's Mask which has been tested and which meets NEDU performance goals (4). Since the MK 1 Mod S has larger gas passages in the sideblock and is otherwise mechanically identical to the MK 1 Mod 0 Diver's Mask, it can be assumed that performance will be no worse than the MK 1 Mod 0 Diver's Mask.

Superlite 17B Description

The SL17 consists of two assemblies (Fig. 1). The first is a weighted fiberglass hat with a removable helmet liner, a tightly fitting oronasal mask, a demand regulator, side block assembly, free flow defogger valve, microphone, and earphones. The oronasal mask has a one-way valve which permits gas flow from the helmet cavity to the oronasal cavity. The valve provides egress of gas from the helmet when the free-flow defogger valve is opened either to clear the faceplate or in case of failure of the demand regulator. The helmet liner has space for extra foam pads and is designed to fill much of the space within the helmet, giving a snug fit to the diver's head. The regulator can be adjusted by the diver to set inspiratory effort to his comfort. The second assembly is a neck dam and yoke which clamps to the hat. It is designed to prevent water entry to the hat in any diver attitude, and the neck dam is flexible to permit the hat to move with the diver's head. The whole unit weighs about 24 pounds dry, and has essentially neutral buoyancy in the water.

MK 1 Mod S Diver's Mask Description

The MK 1 Mod S is an open circuit, surface supplied full face mask which is in current Fleet use (Fig. 2). It has a neoprene hood and adjustable

rubber spider to hold the mask in place. The mechanical systems are very similar to the SL17 and in some cases interchangeable. The MK 1 Mod S differs from the more widely used MK 1 Mod 0 Diver's Mask primarily in having larger gas passages in the sideblock assembly, and is intended for the greater depths of saturation diving.

MATERIALS AND METHODS

The studies were carried out during two days of a twenty-nine day helium-oxygen saturation dive in the OSF. The chest level of the Diver-Subject in the wet pot of the OSF was at an equivalent depth of 850 FSW. A new SL17 was used after routine checking. A MK 1 Mod S used in regular service by NEDU was overhauled and checked to meet specifications. In addition, the MK 1 Mod S was modified by adding two devices which are standard on the SL17; a Whisker Kit exhaust bubble deflector, and an Air Train which distributes gas evenly over the face port when the defogger is turned on. Both units have provisions in the side block assemblies for come-home bottle connections, but these were blanked off.

Water temperature was 72°F (22°C) and the Diver-Subjects wore 1/4" neoprene wet suits. A 30-minute graded exercise was used to assess ability of the SL 17 to adequately support a working diver. Diver work rate was provided by a specially designed electronically braked pedal mode ergometer (Warren E. Collins, Braintree, MASS) modified for submerged use (5,6). Studies were done with the diver in a 45° head-up position for both the SL17 and the MK 1 Mod S and in a 45° head-down position only in the SL17 in order to test sealing of the neck dam. Graded exercise consisted of a 4-minute rest period followed by 6-minute work periods of 50, 100, and 150 watts, separated by 4-minute rest periods. Both units were supplied with a breathing mixture of 98.5% helium and 1.5% oxygen, at 165 psig overbottom pressure. Previous studies using

similar methods showed an estimated oxygen consumption while pedalling at 150 watts of approximately 3 liters per minute (7).

Subjects

The Diver-Subjects were four well trained, experienced U.S. Navy divers ranging in age from 29 to 33 years. All were physically pre-conditioned by an 11 week program of calisthentics, runs up to 4 miles a day and 30 minute graded exercises on a bicycle ergometer, 5 days a week. During the training period the Diver-Subjects made test pool dives and 30 FSW bounce dives with the SL17 and MK 1 Mod S for thorough familiarization.

Instrumentation

Gas samples from the oronasal and helmet cavities were obtained by capillary sample lines with micrometering valves to give sampling rates of 600 to 2700 cc/min (STPD). The delay time from the helmet to the Mass Spectrometer was less than 3 seconds which provided rapid response to variations in gas composition without significant mixing in the sample line. The gas samples were analyzed by one or two Mass Spectrometers (Perkin-Elmer modified Model MGA-1100). Breath-by-breath curves were recorded on a Gould 8-channel strip chart. End tidal P_{CO_2} ($P_{ET_{CO_2}}$) was measured during the last 30 seconds of each rest or work cycle. This value approximates alveolar P_{CO_2} (8).

The inspiratory/expiratory pressure differential was measured at the oronasal mask (SL17 and MK 1 Mod S) and in the SL17 helmet by differential pressure transducers (Validyne DP-9 with 1.25 psi diaphragms) referenced to ambient water pressure at the level of the mask (Fig. 3,4). These transducers were calibrated by a water manometer before each study.

Experimental Procedures

Before each dive with the SL17, each Diver-Subject filled the helmet liner with open cell foam inserts to give a snug helmet fit and a tight oronasal seal. Each of the Diver-Subjects did three separate graded exercises, one with the SL17 at 45° head-up position, one with the SL17 at 45° head-down position, and one with the MK 1 Mod S at 45° head-up position. During the initial rest period, the Diver-Subject adjusted the demand regulator Dial-a-Breath to comfortable breathing effort but no other attempt was made to standardize regulator setting. Divers were instructed not to turn the free-flow defogger valve on except in an emergency.

Following the exercise, the Diver-Subject was interviewed for his subjective evaluation of communication quality, breathing effort during work, comfort, oronasal fit, water leakage, and general opinion of the unit.

RESULTS

Table 1 summarizes the CO_2 levels in mmHg partial pressure for all runs during the last 30 seconds of the rest or work cycle, taken from either the oronasal or helmet. The oronasal $P_{ET_{CO_2}}$ increased slightly as expected during heavier work and there was no significant difference with position of the diver or between the SL17 and the MK 1 Mod S. The helmet P_{CO_2} increased slightly after beginning work and did not increase significantly with increasing work levels.

The pressure differentials from full inspiration to full expiration (ΔP) are illustrated in Table 2. Oronasal ΔP is a qualitative measurement of breathing resistance and can be compared to ΔP measurements taken under similar conditions of gas density where flow measurements were also taken. In

this way actual breathing resistance can be estimated for the SL17 and MK 1 Mod S. The oronasal Δ P during the SL17 head-up run for one of the Diver-Subjects was markedly different from the mean, being 18, 28, 29, and 30 cm H_2O at rest, 50 watts, 100 watts, and 150 watts respectively. The helmet Δ P of this diver was very close to the mean at all work rates. He did not complain of dyspnea.

All Diver-Subjects felt comfortable in the helmet, completed all graded exercises, and had no shortness of breath in either UBA at the workrates tested. During one head-down run the SL17 neck seal leaked slightly, resulting in a small amount of water in the helmet, but this did not interfere with the Diver-Subject performance. Two subjects said that the SL17 was a little more awkward than the MK 1 Mod S when making rapid turning motions.

The earphones supplied with the SL17 worked well and the Diver-Subjects reported that hearing communications from the surface was superior to the MK 1 Mod S.

The microphone supplied with the SL17 worked well during the shallow work up dives but did not give adequate communications at 850 FSW. The high frequency response subjectively appeared to be poor although no frequency measurements were taken. A substitute microphone identical to that used in the MK 1 Mod S was used for all graded exercises and gave excellent results. This custom-made microphone is a ceramic microphone with preamplifier designed by Naval Coastal Systems Center, Panama City, Florida, and is available in various mechanical configurations to fit the MK 1 Mod S and other diving equipment.

DISCUSSION

The DCIEM studies (3) of CO_2 toxicity in the SL17 showed the following five problem areas:

1. a. The DCIEM study noted that a poor fit of the helmet liner permitted a loose oronasal mask fit. Proper packing of the liner gave a good oronasal mask fit.

   b. In the NEDU study, the Diver-Subjects carefully packed the helmet liner to fit, using extra foam when required.

2. a. In the DCIEM study the standard oronasal mask did not fit all size faces well and several different masks were tried.

   b. In the NEDU study the oronasal mask supplied with the SL17 comfortably fit the four divers who tested it.

3. a. The DCIEM study found that a non-compressible, thin rubber neck dam was too compliant, allowing a tidal flow between the helmet dead space and the oronasal even with a good oronasal fit. They stated that the pliability allowed a tidal flow between the helmet dead space and the oronasal as the resistance to movement of the seal was observed to be less than the cracking resistance of the regulator in the demand mode or to the exhaust mushroom valves. A neck dam of 1/4" neoprene solved the problem.

b. The neck dam supplied with the helmet and used in the NEDU study was 1/4" neoprene. The DCIEM study suggests that gas flow from helmet dead space is around the oronasal mask seal during inhalation. Since there is a low resistance one way valve permitting flow from helmet space to oronasal it is likely that a highly pliable neck seal allows helmet dead space to fill with gas leaked by the oronasal seal and this gas then flows back into the oronasal through the oronasal valve during inspiration. Leaking by the oronasal seal would be aggravated by excessive resistance in the regulator exhaust valve. The worst case situation would be failure of the oronasal valve in the wide open position, permitting free flow of gas between helmet and oronasal. The volume of rebreathed gas would depend on dead space in the helmet and neck area, and in the compliance of the neck seal. NEDU did not test the SL17 with the valve removed to simulate a worst case condition, and such a test may be appropriate in the future.

4. a. In the DCIEM study poor helmet balance tended to pull the front of the helmet up, displacing the oronasal, and particularly after long dives, cause neck muscle soreness.

b. This problem was not observed in the NEDU study which involved dives of only 30 minutes. The manufacturer has different, interchangeable helmet weights available.

5. a. In the DCIEM study the improper adjustment of the second stage regulator caused excessive breathing resistance.

b. In the NEDU study the Diver-Subjects were instructed to set the second stage regulator Dial-a-Breath to achieve comfortable breathing with both the SL17 and the MK 1. These settings may change from diver to diver, with position of the diver, and with water depth.

Increased breathing resistance at a fixed P_{CO_2} can cause a decrease in effective pulmonary ventilation. A decrease in ventilation is accompanied by increased CO_2 retention (9). Carbon dioxide retention causes a variety of problems including reduced exercise capacity, depression of central nervous system function; and increased susceptibility to both oxygen toxicity and decompression sickness (10). Breathing resistance was not measured directly in the present study but was estimated by comparing to other underwater breathing devices under similar conditions of gas density and exercise. A study done at 650 FSW using a semi-closed mixed gas UBA and a similar graded exercise program showed an average P of 26 $\pm$ 4 at a 150 watt work rate, with a P_{CO_2} of 56.2 $\pm$ 9.1 mmHg (11).

In the present study maximum $P_{ET_{CO_2}}$ at 150 watts was 55.2 $\pm$ 5.9 mmHg for the SL17 in head-up position, 48.0 $\pm$ 9.7 mmHg for the SL17 in the head-down position, and 57.5 $\pm$ 8.2 mmHg for the MK 1 Mod S. These P_{CO_2} levels support the conclusion that the breathing resistance of the SL17 is not significantly different from the MK 1 Mod S at the work rates tested.

At 132 FSW, air has a gas density similar to the HeO_2 gas density at 850 FSW. NEDU Report 3-81 (12) established a performance goal for an umbilical

supplied open circuit demand UBA as 0.18 kg.m/l on air at 132 FSW and 62.5 liters per minute respiratory minute volume. This corresponds to approximately 12.0 cm H_2O exhalation pressure and (-) 9.0 cm H_2O inhalation pressure. The expiratory and inspiratory pressures in cm H_2O plotted against work rate are shown in Figure 5. These pressures compare well with the unmanned data on the SL17 (1).

The mean ΔP for the SL17 in the head-up position would be somewhat lower if the run previously described which exceeded two standard deviations of the means of the other three runs were excluded. The new means and standard deviations at rest, 50, 100, 150 watts would be, respectively, 8 $\pm$ 3.5, 10.3 $\pm$ 2.5, 14.7 $\pm$ 4.2, and 16.7 $\pm$ 3.5. The reason for the variation in the one run cannot be exactly determined but probably is due to error in calibration of the pressure transducer or due to non-optimum adjustment of the Dial-a-Breath. The Diver-Subject, however, did not complain of dyspnea.

The accumulation of CO_2 in a helmet can be a limiting factor in diver work and diver safety. In a helmet supplied primarily with a demand mechanism, there must be a method of ensuring that the major portion of inspired gas is freshly supplied from the demand mechanism. An oronasal mask which does not permit significant leakage between the dead space in the helmet is a necessary part of the SL17. Under the conditions tested the oronasal mask functioned well. These conditions included education of the diver in packing the helmet liner to push the face forward into the oronasal mask, and use of the standard, low compliant 1/4" thick neoprene neck dam. The slow rise of CO_2 in the helmet is expected in the presence of even a small leak between oronasal space and helmet space, since exhaled gas which contains CO_2

will gradually replace the existing gas in helmet dead space, and is not significant unless re reathing from the helmet occurs. Inspection of the breath-by-breath CO_2 levels showed that the oronasal P_{CO_2} remained near zero for most of inspiration. A typical pattern is seen in Figure 6.

SUMMARY

In summary, both the SL17 and the MK 1 Mod S can adequately support a working diver at 850 FSW. The SL17 has breathing resistance characteristics not significantly different from the MK 1 Mod S. Potential problems with CO_2 accumulation and rebreathing were not encountered, probably because of careful attention to helmet fit. The microphone supplied with the SL17 was replaced with a Navy model which worked well in the OSF communication system. Hearing by the Diver-Subjects was subjectively better in the SL17 than in the MK 1 Mod S. The SL17 has the obvious advantage of a hard protective helmet and a dry head environment, although this was not tested objectively.

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TABLE 1

CO_2 Levels (mmHg)

End Tidal CO_2 (mmHg) in Oronasal Mean $\pm$ Standard Deviation			
Work Rate (Watts)	SL 17 45° Head-Up	SL 17 45° Head-Down	MK 1 45° Head-Up
Rest	42.0 $\pm$ 3.1	45.2 $\pm$ 7.6	49.1 $\pm$ 1.3
50	51.1 $\pm$ 6.5	51.4 $\pm$ 8.2	52.4 $\pm$ 8.7
100	51.4 $\pm$ 6.7	54.4 $\pm$ 8.6	55.4 $\pm$ 8.7
150	55.2 $\pm$ 5.9	48.0 $\pm$ 9.7	57.5 $\pm$ 8.2

Helmet Mean CO_2 (mmHg) Mean $\pm$ Standard Deviation		
Work Rate (Watts)	SL 17 45° Head-Up	SL 17 45° Head-Down
Rest	17.6 $\pm$ 6.8	17.5 $\pm$ 3.8
50	24.8 $\pm$ 4.4	27.2 $\pm$ 5.0
100	24.9 $\pm$ 5.3	27.0 $\pm$ 6.7
150	26.0 $\pm$ 3.8	31.2 $\pm$ 6.2

TABLE 2

Pressure Differential (ΔP)
Mean value in cm $H_2O \pm$ Standard Deviation

ORONASAL

Work Rate (Watts)	SL 17 45° Head-Up	SL 17 45° Head-Down	MK 1 Mod S 45° Head-Up
Rest	10.5 ± 5.7	13.3 ± 2.8	19.3 ± 6.5
50	14.8 ± 9.1	12.8 ± 4.6	21.5 ± 4.2
100	18.3 ± 7.9	16.0 ± 4.7	22.5 ± 2.4
150	19.5 ± 6.4	16.8 ± 5.3	24.3 ± 3.4

HELMET

Work Rate (Watts)	SL 17 45° Head-Up	SL 17 45° Head-Down
Rest	9.5 ± 4.0	10.0 ± 3.7
50	12.0 ± 3.3	9.5 ± 2.4
100	14.8 ± 3.4	11.3 ± 2.2
150	15.5 ± 3.3	10.0 ± 2.3

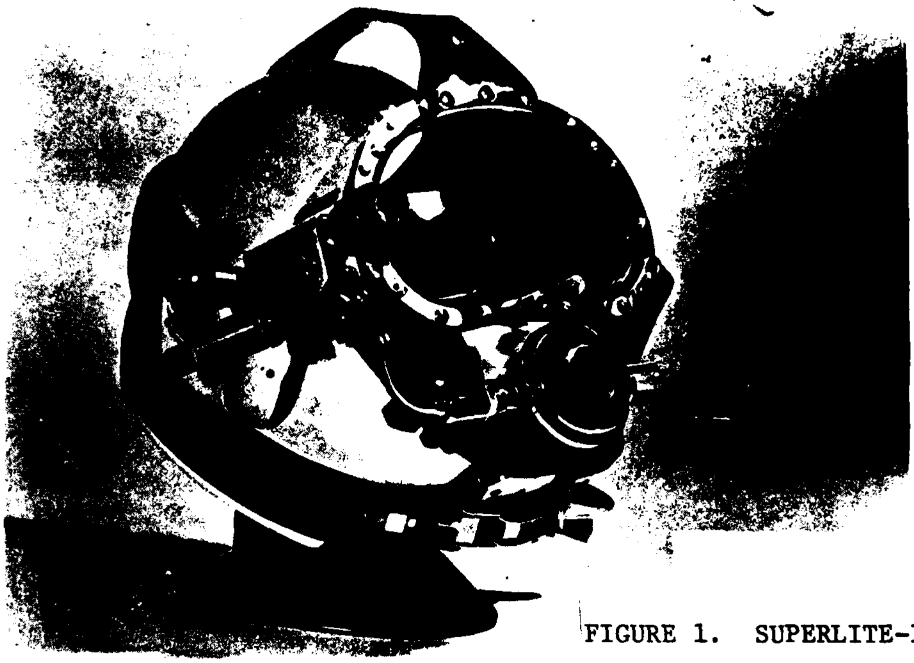

FIGURE 1. SUPERLITE-17B

FIGURE 2. USN MK-1 MOD S DIVER'S MASK

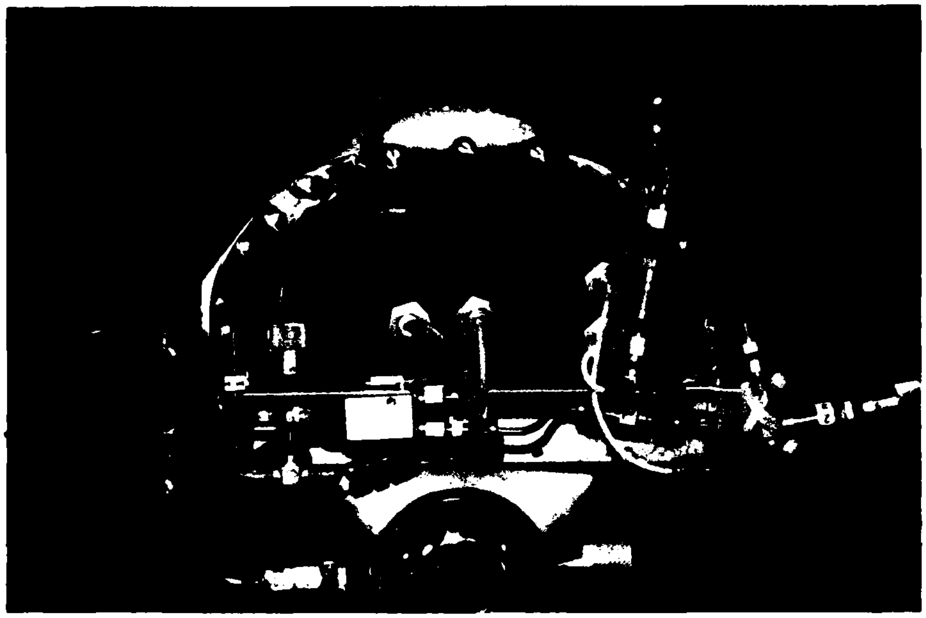

FIGURE 3. INSTRUMENTED SUPERLITE 17B

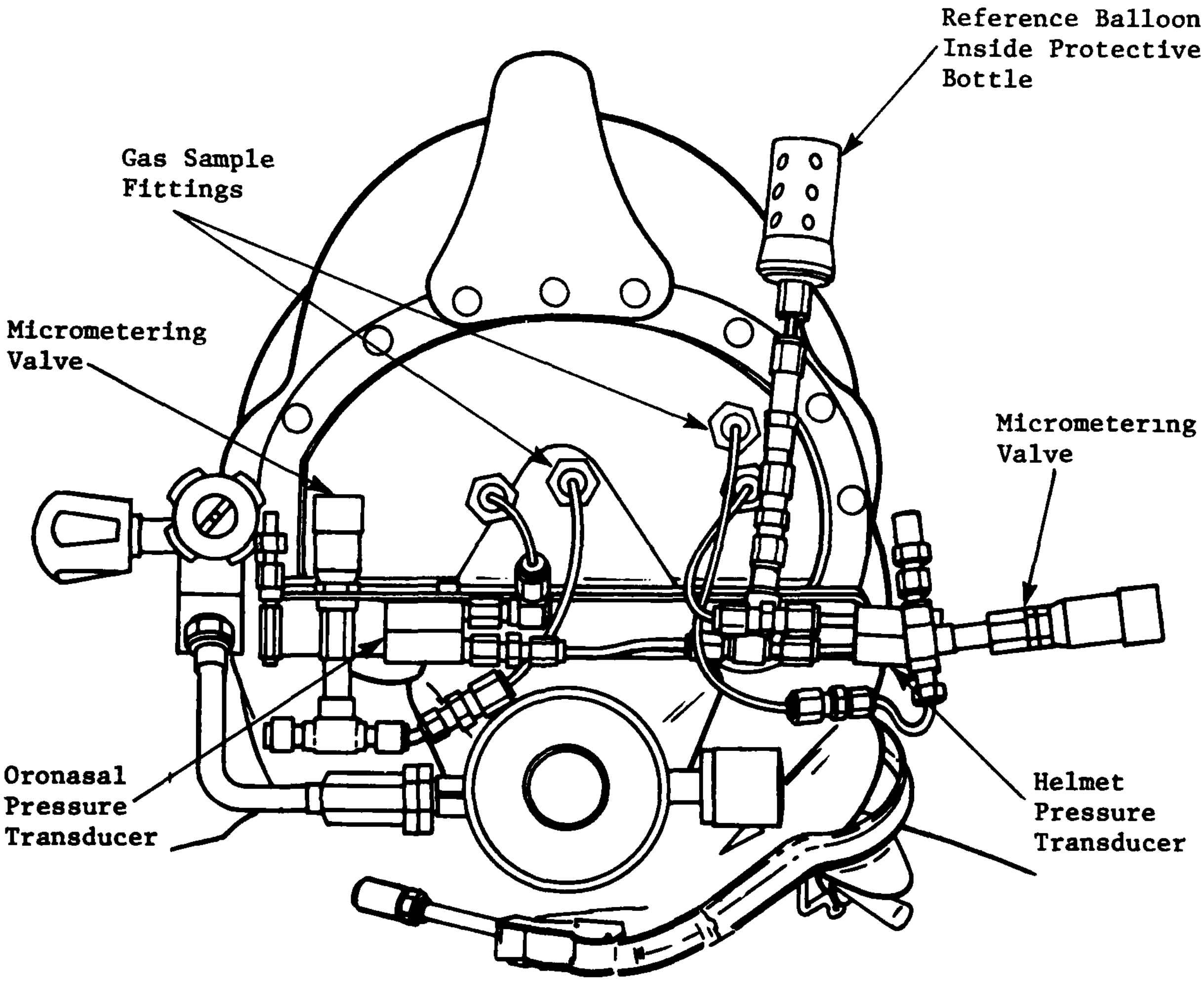

FIGURE 4. DIAGRAM OF INSTRUMENTED SUPERLITE 17B

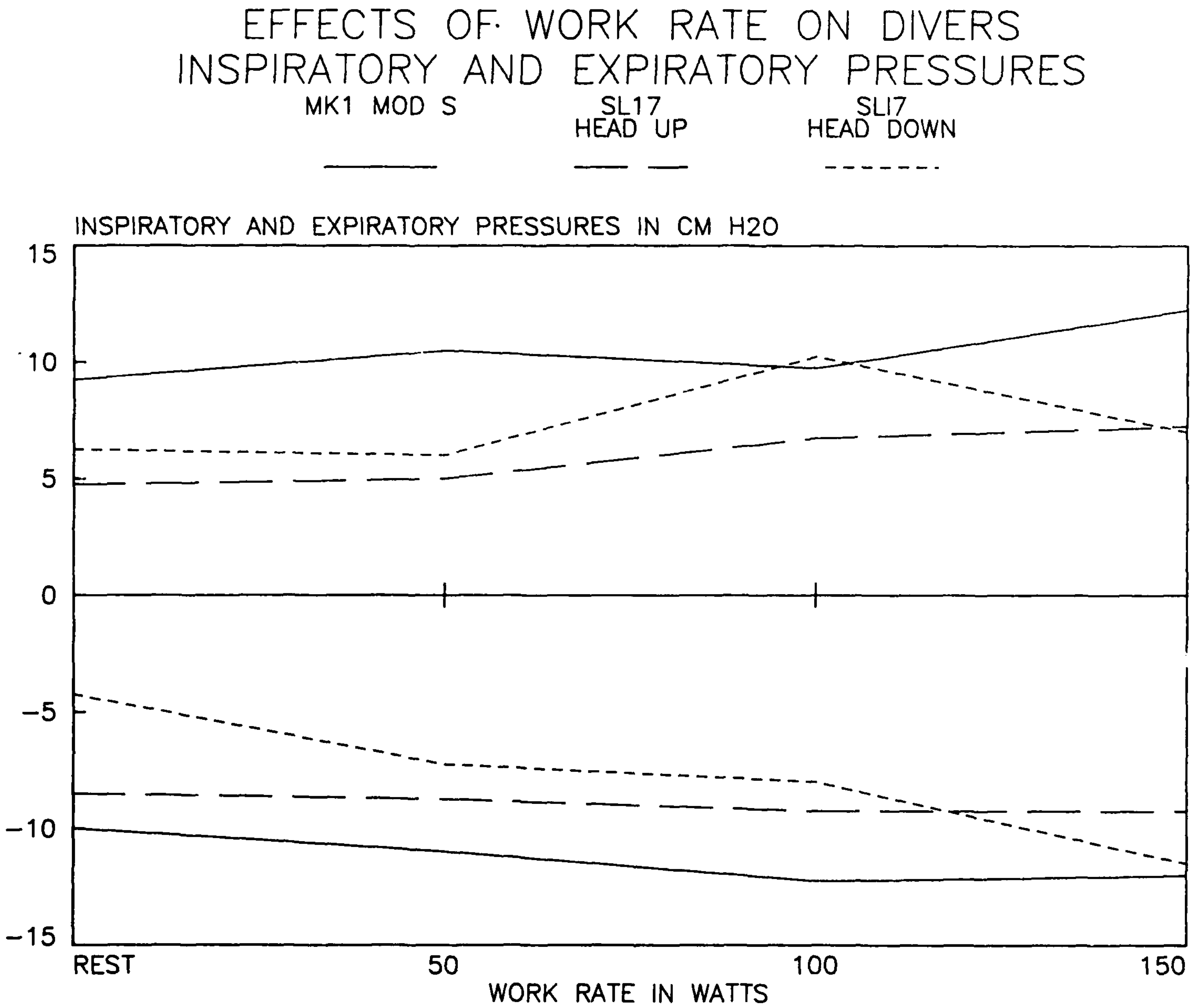
EFFECTS OF WORK RATE ON DIVERS
INSPIRATORY AND EXPIRATORY PRESSURES
MK1 MOD S
SL17
HEAD UP
SLI7
HEAD DOWN
INSPIRATORY AND EXPIRATORY PRESSURES IN CM H20
15
10
5
0
−5
−10
−15
REST
50
100
150
WORK RATE IN WATTS

FIGURE 5

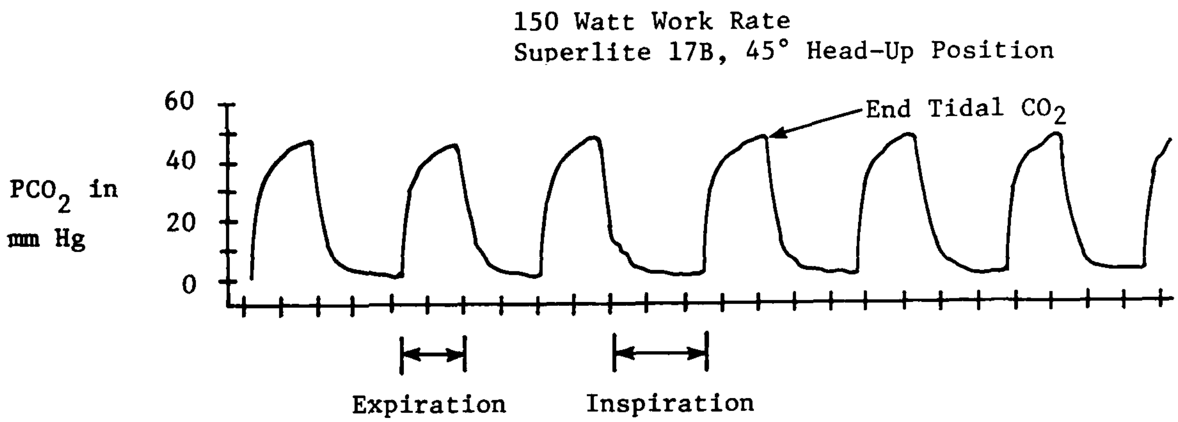

FIGURE 6. TYPICAL BREATH-BY-BREATH PCO_2

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